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Earthworm as ecofriendly resource: A review

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Abstract
Biological resources are very important as they safe our future food security. But advancement in technologies has changed the complexion of the present era. That's why we started realizing bioresources and economics as an integral part of our life. Soil fauna plays a very vital role in improving soil texture which help in creating enhanced condition for the growth of useful organisms to fight against plant disease. The success of soil or land reclamation depends upon identification of proper species suitable for different agro climatic zones of a country and their threshold number in a particular zone. Such practices are already a way to improve the quality of soil. Still we are allowing them to be destroyed. Among all soil faunas, no animal has potential as earthworm for human beings and his environment. These vermi-resources possess extensive and dynamic potential like waste recycling, biofertilizer generation, land restoration, and sustainable environment. Recently vermiresources technology is an ecological, economical, and socially acceptable technology of major importance to agriculture and the environment. The present review assesses species diversity, ecological categories and earthworm species used for waste material management, different methods of vermicomposting, characteristics of vermicompost, and their future prospects. Waste decomposition by vermiculture helps to recycle soil nutrients and convert waste into valuable resources.

Keywords: Earthworm, ecological categories, diversified potential, vermitechnology

Introduction

In India green revolution was initiated in the 1960s to boost food production without realizing its side effects. The today requirements are all about the need for ecological balance for maintaining the sustainable agriculture. It is inevitable that biological methods are important for the up gradation of conservation of soil to secure food possibilities. The potentials of earthworm as a biological tool is significant in organic farming and sustainable development (Bhardwaj et.al 2015) [3, 8]. Earthworms are important vermiresources which form major soil fauna, constituting 80% of soil invertebrates. Vermiculture technology is crucial to the second Green Revolution, offering a sustainable alternative to chemical fertilizers that can have a negative impact on both the farmers and their farmlands. A critical harm to the environment is also caused by organic solid waste. Solid waste management technology (composting and vermicomposting) are today regarded as a clean and sustainable method for managing organic waste (Kaur 2020) [25]. Vermicomposting is getting recognition for its eco-friendly approach and is now a key component of modern organic farming. Its by-products (vermicompost and vermiwash) are easy to produce and highly effective in enhancing soil texture, fertility, and plant growth.

Earthworms are key members of the soil fauna and along with other organisms constitute the soil community. These vermiresources has different feeding habits and for identifying and classifying them researcher should know the various ecological categories (which mainly depend upon their feeding habits). Various categories were assigned to earthworm's time to time by the taxonomists. Detritivores are the organisms that feed at or just below the soil surface, mainly on decomposing plant material and dead roots in organic-rich topsoil, while those that form deep burrows and consume large amounts of nutrient-rich soil are categorized as geophagous. Earlier, Graff (1953) distinguished Lumbricids into two groups: Deeply pigmented having high rates of reproduction, and un-pigmented forms with low reproduction rate.

The pigmentation in surface dwelling species provides protection for them from U.V. rays from the sun. Subsequently various workers identified important features to distinguish between surface dwelling and soil dwelling earthworms. After that Perel (1977) classified Lumbricids into humus formers (which feed upon slightly decomposed plant matter) humus feeders (which feed upon the advanced stage of decomposed plant material that has been incorporated into soil.

Likewise, depending upon lifestyle of earthworms, the classification was given by Bouche (1977) [11] into three groups epigeics (litter dwellers, no burrow formation, very active and deeply pigmented (Fig1).

Fig 1: *Dichogaster bolaui* *Perionyx simlensis* *Eisenia fetida*

Next category is of endogeics (top organic mineral soil dwellers, construct horizontal and branching burrows, less active, weakly pigmented (Fig.2).

Fig 2: *Eutyphoeus incommodus* *Drawida nepalensis*

Lastly one more important vermicomposting category is anecies (Deep burrowers, construct vertical burrows (drilosphere), active, slightly pigmented at anterior and posterior end (Fig3).

Fig 3: *Lampito mauritii*

The earthworm’s classification currently used is a modern revision of classical system which was further refined by Blackemore (2000) that is historically proven and widely accepted classification In traditional classification systems, earthworms were placed in the order Opisthopora (position of their male pores behind the female pores) and referred to as megadriles, distinguishing them from microdriles found in semi-aquatic families such as Tubificidae, Lumbricidae, and Enchytraeidae.".

Basic classification of class Oligochaeta (Brinkhurst and Jamieson; 1971)

Phylum Annelida (Metameric segmentation)

↓

Class Oligochaeta (Based on reproductive system and somatic characters)

↓ 3 Orders

1. Lumbriclida 2. Moniligastrida 3. Haplotaxida

↓ 3 Families

1. Haplotaxina 2. Tubifician 3. Lumbricina

(Microdrile) (Earthworms)

↓ 3 Superfamilies

Alluroidoidae 2. Lumbricoidae 3. Megascolecidae

Taxonomy

The Oligochaeta fauna, particularly earthworms have drawn the attention of several taxonomists in many parts of the world. The first systematic study of Oligochaeta fauna in the Indian subcontinent was explained by Templeton (1844) [44]. In this description of *Megascolex caeruleus* from Sri-Lanka was given. Subsequently descriptions of several Indian species were published by various taxonomists. Michaelsen’s monograph on Oligochaeta that provided descriptions of all known species in the world. Although the monograph was somewhat out-dated but still it gives a valuable guidance for oligochaeta taxonomy. He also published a consolidated account on the Indian subcontinent oligochaetes. Stephenson (1923) [43] produced a volume on the Oligochaeta fauna under “The fauna of British Indian, including Ceylon and Burma " series. The information on the Burmese earthworms was consolidated by Gates (1972) [18]. Julka (1988) [23], also contributed a Monographic work on the family Octochaetida under the “Fauna of India” series. Comprehensive taxonomic and distribution survey of oligochaetes particularly of earthworms was done by many researchers (Stephenson, 1923; Gates. 1972) [18, 43]. The publication of papers (Kumar and Tripathi, 2021; Bhardwaj and Sharma, 2016; Sharma and Bhardwaj; 2014; Tripathi and bhardwaj, 2005; Julka & Paliwal, 2005; Julka, 1988; Julka and Senapati, 1987) [2, 4, 22, 23, 24, 28, 37, 41, 46] fill the much-needed gap in taxonomic and distribution studies which can be taken as the most recent.

Earthworm Diversity

India is one of the mega biodiverse country and only 11.1% of earthworm diversity is available out of total global earthworm diversity (Bhardwaj and Sharma, 2016; Rajkhowa et.al., 2015) [2, 4, 38]. Approximately 4200 species of Oligochaetes are known globally (Munnoli et.al.,2010) [33]. India serves as a biogeographical gateway for the richest biodiversity in the world and is regarded as a vital center for the evolution of many unique species. However, due to the inaccessibility of certain terrain regions, the diversity of earthworms in this ecological area remains unexplored. Hence, further investigation of these remarkable soil organisms is essential. This review aims to consolidate existing information on earthworm diversity from various regions across India. Earlier Julka and Paliwal, (2005) [22, 37] gave the data of 419 species and 67 genera. Out of 20 families in the world, Julka (1993) gave the account of 10 families recorded from Indian Subcontinent indicating a high degree of diversity as compared to other areas. They are Acanthodrilidae, Almidae, Criodrilidae, Eudrilidae, Glossoscolecida, Lumbricida, Megascolecidae, Moniligastridae, Ocnerodrilidae, Octochaetidae.

Thereafter, Julka *et al* (2009) reported 590 species of earthworm from India.

Various studies were conducted on earthworm diversity from different parts of India and the results are summarized in Table1.

Table 1: The record of earthworm species from different parts of the country

Sr.No.	Localities	No. of Species (with families)	References
1.	Uttar Pradesh	11 sp	Singh 1977 [42]
2.	Western Ghat (South India)	28 sp., 3 families	Balanchart and Julka (1997)
3.	Rajasthan (Jodhpur Distt.)	9 sp., 4 families	Tripathi and Bhardwaj (2004c) [45, 47, 48]
4.	Western Himayalan States	51 sp., 7 families	Paliwal and Julka (2005) [22, 37]
5.	FootHills of Shivalik Himalaya	6 sp., 2 families	Namita & Swati (2009) [36]
6.	Doon Valley of Western Himalayan	12 sp., 4 families	Verma and Shewata (2010) [49]
7.	Gangetic Plain of Uttar Pradesh	11 sp., 2 families	Verma *et al*., (2010) [49]
8.	Kashmir Valley	8 sp., 3 families	Najar and Khan (2011)
9.	Nilgiri Biosphere Reserve Western Ghat	12 sp., 5 families	Chadran *et al*., (2012)
10.	Gulbarga city (Karnataka)	3 sp., 2 families	Hatti (2013) [20]
11.	West Tripura (Rubber Plantation)	12sp., 5 families	Chaudhary etal. (2013)
12.	Eastern Haryana	9sp., 3 families	Sharma and Bhardwaj (2014) [41]
13.	Assam	17 sp., 6 families	Rajkhowa *et al*. (2015) [38]
14.	South 24 Parganas West Bengal	6 sp., 2 families	Goswami and Mondal (2015)
15.	Eastern Haryana (Sugar- belt)	3sp., 3 families	Bhardwaj and Sharma (2016) [2, 4]
16.	Arunachal Pradesh	12 sp., 8 families	Zothansanga etal. (2020) [51]
17.	Himachal Pradesh	32sp., 7 families	Ahmed *et al*. (2020)
18.	Rajasthan	18sp., 5families	Kumar and Tripathi (2021) [28]
19.	Uttarakhand	52 sp. 8 families	Miglani *et al*. (2022) [31]
20.	Haryana	1sp.	Bhardwaj and Sharma (2023) [5, 6]

The earlier literature stated that native species were approximately 89% of the total earthworm diversity in India, suggesting that their habitats remained undisturbed. Significant alterations to natural habitats often lead to the introduction and spread of non-native species. Approximately 45 exotic peregrine forms were introduced into India (Julka, 1988) [23]. Out of the recorded species of earthworms in India majority of them belong to endogeic or geophagus in nature (Julka *et al*., 2009).

Key to identification of some earthworms (bhardwaj *et al*., 2017) [7]

(Based on external characters)

1. Setae 4 pairs on each body segment (lumbricine) ………………………. 2

Setae numerous on each body segment (perichaetine).……………….... 6

2. Male pores inconspicuous, paired setae alternating between dorsal and ventral positions on posteriad segments ………... ….. *Pontoscolex corethrurus*

Male pores conspicuous, paired setae in longitudinal rows throughout the body ………....
…..………...…..………...…..………...….…….. 3

3. Dorsal pores and spermathecal pores absent, male pores combined with prostatic pores on segment xvii, seminal grooves lacking ………... ….. ………...….. ……...….. ……..…. *Ocnerodrilus occidentalis*

Dorsal pores and spermathecal pores present, male pores on segment xviii, prostatic pores on segments xvii and xix at ends of seminal grooves ………..….....…. ……….... ………....………...……………. 4

4. Clitellum on segments xiii, xiv-xviii, xix, xx, female pore single, spermathecal pores at intersegmental furrows 7/8/9 ……………..... ………..... ………..…...... ………...... ………... ……. *Dichogaster bolaui*

Clitellum on segments xiii-xvii, female pores paired, spermathecal pores on segments viii and ix ……….....……….....….....………..………. 5

5. Short and thin worms, length less than 40 mm, diameter less than1.5 mm; spermathecal pores just posterior to intersegmental furrows 7/8/9 ………...………....………...………......... *Ramiella bishambari*

Long and stout worms, length more than 40 mm, diameter more than 2 mm; spermathecal pores close to setal arcs of segments viii and ix ……………......……….....………....……….....
Octochaetona paliensis

6. Genital papillae present ……….....……….....……….....………...………. 7

Genital papillae absent ……….....………....………...………..…..…. 8

7. Spermathecal pores 4 pairs, at furrows 5/6/7/8/9; male pores in copulatory pouches; genital papillae paired on segments xvii and xix ……………...………...…....………......………......
Metaphire posthuma

Spermathecal pores 2 pairs, at furrows 5/6/7; male pores not in copulatory pouches; genital papillae transverse rows on segments xviii and xix; paired usually on segment vii, single usually on segments vii and viii ………...………...…………... *Amynthas morrisi*

8. Body colour greyish or brownish, length more than 90 mm, first dorsal pore in intersegmental furrows 10/11 or 11/12 or 12/13, female pores paired, nephridiopores inconspicuous ……….. *Lampito mauritii*

Body colour dark purple, length less than 90 mm, first dorsal pore in intersegmental furrow 3/4or 4/5 or 5/6, female pore single, nephridiopores obvious, alternating between dorsal and ventral ranks ………......………......………......………......………......
Perionyx sansibaricus.

Distribution

The diversity of earthworms varies significantly across different habitat types (Table 2). They thrive in soils that offer adequate moisture and a reliable food source. The majority of earthworms were documented in forests, grasslands, farmlands, orchards, gardens, nurseries, and greenhouses. A few species have been recorded to live under snow on high mountains (Julka 1988) [23]. Most earthworms were recorded where soil is alkalo philous in nature (Sharma and Bhardwaj 2014: Bhardwaj, *et al*., 2017 and Bhardwaj and Sharma, 2016) [7, 2, 4, 41]. Moisture acts as a limiting factor in the distribution of earthworms. The temperature of the soil has a crucial role in maintaining moisture levels and the distribution of earthworms throughout the soil layers. By managing soil temperature, we can effectively enhance soil health and promote a thriving ecosystem.

Most of the species of earthworms prefer soil with a temperature of $10\text{-}35^0$C, moisture of 12-45% pH of about 7, and a C/N ratio of 2-18 (Bhardwaj, 2003). Tripathi and Bhardwaj (2004ab) [45, 47, 48] reported that optimum temperature, moisture content, and pH for *E fetida* were 25^0C, 70%, and 6.5, respectively. However, the optimum temperature, moisture content, and pH for *L mauritii* were 30^0C, 60%, and 7.5, respectively.

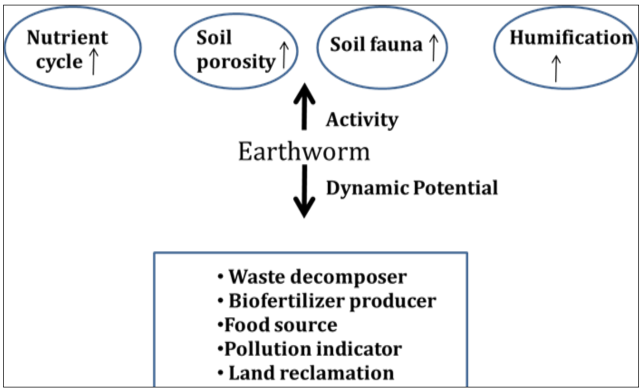
Table. 2. Eco-morphological characteristics with ecological categories of some earthworm species of Rajasthan (Tripathi and Bhardwaj, 2005) [46]

Species	Pigment	Ecological category
1. *P. corethrurus*	Unpigmented	Endogeic
2. *A. morrisi*	Reddish brown	Epi-anecic
3. *M. posthuma*	Brown	Endo-anecic
4. *L. mauritii*	Unpigmented	Anecic
5. *P. sansibaricus*	Dark purple	Epigeic
6. *O. occidentalis*	Unpigmented	Endogeic
7. *R. bishambari*	Light brown	Endogeic
8. *D. bolaui*	Unpigmented	Epigeic
9. *O. paliensis*	Unpigmented	

Generally, earthworms are more active in moist soil than in dry soil (Bhardwaj, et. al 2015) [3, 8]. The carbon to nitrogen (C/N) ratio is the key factor that limits earthworm populations. *L.mauritii* and *P. corethrurus* are often found in soils where the C/N ratio is high while *P. excavatus* is commonly found in soil with a low C/N ratio. *L.mauritii* is known species to tolerate high temperatures in India (Sharma and Bhardwaj, 2014) [41]. The activity of *L maurutii*, *D. calebi*, *D. willsi* and *O. surensis* remains confined at 20 cm depth Soil texture also influences the earthworm population density and species richness. The soils which are deficient in organic matter do not usually support large numbers of earthworms.

Dynamic Potential of Earthworms

Earthworms have diversified potentials and can play an important role for man and the biosphere. They can recycle the organic waste and produce useful material which can be used as biofertilizers. These biofertilizers can replace chemical fertilizers to some extent and create a better environment for the growth of plants. Earthworms are also used as bait for fish and other animals because they have 70-80% protein on a dry mass basis. They are also known to be associated with medicine to cure various diseases since ancient times. In addition to this, earthworms exhibit a remarkable resistance to pesticides and heavy metals. They deal with these challenges by increasing mucus production, reducing locomotion, and raising their reproductive effort until certain concentration limits. The significance of earthworms is undeniable, as they offer many benefits, which can be outlined as follows:



Vermiresources as a biofertilizers producer

The increased in human population has raised the food demand which can be fulfilled by adopting new techniques in agricultural practices. The safest part is organic farming which includes vermicomposting. Charles Darwin (1881) firstly studied the role of earthworm in decomposition process. Later many workers introduced vermiculture by using different organic residues. Biology of some specific earthworm species preferred for vermicomposting. Biodegradation of rural and agro-industries waste, household garbage, and sewage sludge scientifically by earthworms is an attractive preposition to generate valuable organic fertilizer consistent with the minimization of environmental pollution. Here primary decomposers are microorganisms and earthworms act as secondary and main decomposers. The word vermiculture is derived from the Latin word 'Vermis' meaning 'Worms' which involves the mass production of earthworms for waste degradation. This in turn produces organic fertilizer in the form of 'vermicast'. The way worms act on organic matter involves two major processes active phase GAPs (gut-associated processes) in which earthworms ingest and process the organic waste through the guts by modifying microbial activity and maturation phase CAPs (cast-associated processes) in which microorganisms take over the decomposition of the earthworm- processed waste and help in their reduction into valuable products (vermicompost) (Edwards *et al*., 1992). The most important thing is that the length of the active phase depends mainly on the species and their decomposition rate for organic waste materials.

Vermicomposting is a bioremediation involving a biotechnological process. Recycling of wastes through vermitechnology is a vast area in which the biomass of earthworms is used for many purposes. Various steps involved in vermitechnology are as depicted below:

Suitable Earthworm → Species Organic Waste Material (nature of food they prefer) → Vermibed in Manure Tank Harvest → for few days (according to conversion of waste into fertilizer) Worm Biomass (as a feed for poultry → and Aquaculture

Vermicompost and Vermiwash (Plant growth and fertilizer for aquaculture)

The main important point which one should remember is that while providing the feed for the earthworm the ratio of C/N must be maintained. The range should be not more than 1:20 above and the plant will not be able to acclimatized nutrient.

The modern form of practicing vermiculture began gaining traction in the mid-20th century. Some experimental work was done in Holland in 1970 and soon adopted in England and Canada. From then on, it seems to have spread like wildfire – people in the USA, Italy, the Philippines, Thailand, China, Korea, Japan, France, Australia, and even Israel started adopting vermiculture (Edwards, 1988) [17]. Vermiculture experiencing a global resurgence due to its wide-ranging environmental benefits, including waste recycling, soil purification, and the promotion of sustainable agriculture.

All these countries have established set-up vermiculture plants to degrade urban waste, sewage sludge, piggery waste, and Kitchen waste.

India has yet to appreciate the full importance of vermiculture despite the potential for the production of 400 million tons of vermicompost annually from waste degradation (Sinha, 1996). The Indian subcontinent produces a great amount of anthropogenic waste. Vegetables or leaves waste from the major constituents of municipal solid waste (40.15%) and rest are miscellaneous (Bhardwaj and Sharma, 2015; Bhardwaj *et al*., 2015) [3, 8]. In 1998 Government of India announced that those institutes, organization and individuals were get exception from tax liability who is involved in vermiculture on a commercial scale. The Bhawalkar Earthworm Research Institute (BERI) is one of the largest non-governmental organizations involved in vermi-technology at Pune in India. It is operating a plant for the management of municipal wastes. Chennai, Mumbai, Indore, Rajasthan, Haryana, and several other Indian cities are also following the vermitechnology practices for the degradation of organic waste.

Varieties of worms

There are various varieties of earthworm but only some types are of commercial importance. Night crawlers, field worms (also known as garden worms), manure worms and red worms are some categories, out of which only manure and red worms can adapt to live in many different environments and will consume almost any type of organic matter. Epigeic earthworm species are known for their efficiency in decomposition and rapid growth. But, earlier literature has highlighted that endogeic and anecic species primarily function as burrowers, creating mucus-lined tunnels—horizontal in the case of endogeic and vertical for anecic species—within soil systems. These burrows create a micro-environment that promotes microbial colonization, which in turn facilitates nitrogen transformation and the breakdown of other plant-based compounds. Incorporating endogeic or anecic worms into waste decomposition processes not only enhances microbial activity but also rapids the mineralization process (Gajalakshmi *et al*., 2005; Tripathi and Bhardwaj, 2005) [46].

Besides this, every type of soil has different species of earthworms. As we mentioned earlier, soil texture also plays a significant role in earthworm's fauna diversity, hence choosing a local or native species for local soil and for vermicomposting is the 1st step. There is no need to buy earthworms from elsewhere. According to Ismail (2001) the local species which can be used are *Perionyx excavatus* and *Lampito mauritii*. Excluding these two, other earthworm species which are recommended for vermiculture in India are *Eisenia fetida*, *Eudrilus eugeniae, Perionyx sansibaricus* etc.

Previously, vermireactors were based on the use of single earthworm species (monoculture) i.e., epigeic/endogeic/anecic. Recently many workers have been focusing on polyculture-based vermireactor (combination of two or three earthworm species) to see its efficiency to manage various organic wastes (Table 3). Considerably, the polyculture based vermireactor is still a promising field of research in vermin-technology.

Table 3: Type of reactor and species used for vermi-processing of organic wastes

Sr. No.	Reference	Substrate	Sp. Used	Ecological Category	Reactor Type
1.	Tripathi & Bhardwaj (2004a) [45, 47, 48]	Mixed bedding	*E. fetida* *L. mauritii*	Epigeic Anecic	Monoculture Monoculture
2.	Tripathi & Bhardwaj (2004b) [45, 47, 48]	Kitchen waste and cowdung	*E. fetida* *L. mauritii*	Epigeic Anecic	Monoculture Monoculture
3.	Khwairakpan & Bhargava (2009)	Filter mud + Sawdust	*E. fetida + E. eugeniae + P. excavates*	Epigeic Epigeic	Monoculture Polyculture
4.	Bhardwaj & Sharma (2008)	Cowdung	*E. fetida*	Epigeic	Monoculture
5.	Bhat & Limaye (2012) [9]	Kitchen Waste	*E. fetida*	Epigeic	Monoculture
6.	Bhardwaj etal. (2015)	Mango leaf-litter and cowdung	*E. fetida* *L. mauritii*	Epigeic Anecic-	Polyculture
7.	Bhardwaj & Sharma (2015) [3, 8]	Mixed waste	*M. posthuma, P. simlaensis, D. bolaui* D. *nepalensis and O. beatrix,*	Epi- anecic Epigeic Endogeic	Monoculture
8.	Manohar *et al*. 2016 [30]	Plant Debris, Cattle Dung and Paper	*E. fetida*	Epigeics	Monoculture
9.	Ramnarain, etal. 2019 [39]	Dry grass clippings, rice straw and cow manure	*E. fetida + E. eugeniae +P. excavates*	Epigeicsy	Polyculture
10.	Devi and Khwairakpam, 2021	Weed (*Parthenium hysterophorus*)	*E. fetida + E. eugeniae*	Epigeic	Polyculture
11.	Das and Dekh 2021 [14]	Potato	*E. fetida*	Epigeic	Monoculture

Preparation of Vermibed

The setting of vermibed various time to time. The main different methods for setting vermicomposting unit are circular, rectangular, and strip method (Singh 1997, Munnoli 2007) [32, 42]. Besides this, there are various designs for vermiculture units which are mainly based on the topography, type of soil, organic waste material, and amount of rainfall. Depending upon the indoor or outdoor method the vermiunits are set. The various types of waste used by earthworms as food are Kitchen waste **(** Vegetable and fruits peels remain of bread, egg shells; remains of tea and coffee), Garden waste **(** Leaf litters, grasses), Farm wastes **(**Crops residues and straw, sugarcane trash, coir wastes), Animal dung **(**Animal waste and poultry droppings), Sugar mill residue **(** pressed mud cake, bagasse and sugarcane thrash), Municipal waste **(**Garbage and sewage sludge along-with waste from restaurants, cafeteria etc).

All organic wastes need 7-10 days for partial decomposition for stabilization. Generally, vermibeds were prepared in wooden boxes, buckets, plastic trays or it may be earthen pots with a few small holes at the bottom to drain out the extra water. So that excessive water can be prevented. For the preparation of vermibed 3-4 fine sand or layer of garden soil as a base are used. Above these earthworms were introduced. Thereafter about 5-6 cm of cattle dung or any other organic waste material were placed as feed material above earthworms. The moisture of bedding was maintained up to 40-60% by sprinkling water depending upon the season. The whole set (vermibed) was covered with jute bags to retain moisture. In 6-8 weeks, waste had been degraded and converted into a loose, black, granular mass called vermicompost. The watering was stopped for 3-5 days. So that earthworms started accumulating at the base of the container, the upper layer was then removed and dried in the shade. This vermicompost can be used as an organic fertilizer. The pit size should be varied accordingly.

For the success of vermiculture the main factors involved are:

- Constuction and Depth of the pit
- Moisture
- Nature of the feed
- Shade
- Covering the vermibed with jute
- Avoidance of prey
- Selection of the species (exotic or local)
- Selection of organic waste material

Vermicompost as fertilizer cum pesticidal properties:

Vermicompost has the potential to boost the growth of plants during biotic stress. The negative impact of synthetic pesticides has led to an urgent need for a more organic way to control pests. Many workers through their studies explained the role of vermicompost as biopesticidal in suppressing plant pathogens and plant nematodes. The suppression of soil-borne disease is likely due to both biological and chemical factors. Biological factors are mainly attributed to the action of microbial communities inhabiting compost. Chemical factors include physico-chemical properties like organic matter, C/N ratio, total nitrogen, available phosphorous and potassium, etc. Jadhav and Sayyal (2016) showed that the hydrolytic enzyme present in vermicompost is capable of hydrolyzing fungal cell walls proving its biofertilizer cum biopesticide property. Not only this now Neem (*Azadirachta indica*) serve as an excellent fertilizer because it is nutrient rich Their leaves contain azadirachtin, which has insecticidal, fungicidal, bacteriacidal and nematocidal properties (Chaudhary *et al*., 2017). The study on nutrient profile of vermicompost prepared from neem was also revealed by many workers (Kumar etal., 2022). However, the inclusion of neem leaves at a certain concentration may suppress the growth of microorganisms or fungi in vermicompost. The neem chemical composition significantly influences the density of microbial populations and, in turn, affects the enzymatic activity within the vermicomposting system. Few studies investigate neem leaves as a substrate for vermicomposting. There is a need to explore this study.

Status of Vermicompost

Vermicompost benefits agricultural soil by boosting moisture holding capacity, better nutrient retention ability, contributing to better soil structure, and higher levels of microbial activity. Vermiculture technology has several benefits which include natural fertilizers reducing pollution and promoting sustainable agriculture. Vermicomposting might be an efficient technology for providing better NPK nutrition from different organic wastes (Tripathi and Bhardwaj, 2004) [45, 47, 48]. The nutrient content of the vermicompost depends upon the quality of feed materials of earthworms. Unlike raw organic waste, vermicompost is dark, earthy-smelling, and free from foul odors.

Increased amounts of NH_4, NO_3, Mg, K, and P have been identified in earthworm castings as compared to soil by several workers. Enhanced N.P.K contents in vermicompost may be due to microbial enzyme activities while passing through the gut of earthworms. Earthworm vermicompost is proving to be a highly nutritive 'organic fertilizer and more powerful' growth promotes' over the conventional compose and a protective farm input against the 'destructive' chemical fertilizer which has destroyed the soil properties and decreased its natural fertility over the years (Bhat and Limaye, 2012) [9]. The overuse of nitrogen-based fertilizers has resulted in increased levels of inorganic nitrogen in groundwater due to leaching, and in the food chain, posing serious health risks to humans. The conventional composting (which involves the aerobic decomposition of organic materials like cattle dung and municipal solid waste) and vermicomposting (earthworm and their feed) are fundamentally different processes.

Vermiwash

Vermiwash is the byproduct of vermiculture used as organic fertilizer by added directly as a basal treatment in the soil or used as a liquid sprayer to prevent fungal bacterial and other pests (Bhardwaj and Sharma, 2016, Gudeta, *et al*., 2021) [2, 4, 19]. The brownish-red liquid obtained through earthworm-worked soil is referred to as vermiwash. This liquid contains a high concentration of amino acids along with vitamins, growth hormones like 'auxins', cytokines, and nutrients (N, P, Mg, Zn, Ca, Fe, and CV). It also contained plenty of nitrogen-fixing and phosphate-solubilizing bacteria. The bioactive macromolecules through the skin of the earthworm, along with coelomic fluid, and mucus protect the worm from pathogenic soil microbes and thereby free the environment from the disease (Kasahun *et al*, 2021). Besides its application as a fertilizer to enhance crop productivity it can also be applied in disease suppression and pest control due to its antimicrobial and antipest chemicals (Nadane *et al*,2020) [34]. Bhardwaj and Sharma (2016) [2, 4] reported a vermiwash effect on the growth and productivity of moong dal which act as an excellent organic fertilizer. The assessment of vermiwash indicated the presence of micronutrients of significant quality. Farmers from various parts of India, now applying vermiwash along with vermicompost on various vegetables with excellent results. Both biofertilizers contribute macronutrients and micronutrients in amounts that are required by plants (Bhardwaj and Sharma, 2016) [2, 4].

Earthworms as Pollution Controller

Earthworms are often called keystone species. They help keep soil structure, texture, and fertility healthy. People call them "ecosystem engineers" because they affect how organic matter breaks down, how soil forms, and how microbes in the soil work. But strong farming methods, like using chemical pesticides, can really slow them down. Many studies found that pesticides can harm earthworm enzymes, cause more deaths, slow growth and breeding, change how they eat, and finally threaten the species and their job in nature. Pesticides can quickly hurt earthworms because their skin is thin and they touch the soil directly through their gut (Yadav *et al*., 2023) [50]. After entering the body, heavy metals can bind to various macromolecules such as nucleic acids, proteins, and lipids in cells. These negative effects of heavy metals on earthworms can have excessive negative effects on community stability as well as serious ecological consequences for the entire terrestrial ecosystem. Therefore, heavy metal pollution of soil presents a significant threat to earthworms, reducing their efficiency and posing a risk to the environment and human health. Both natural sources and anthropogenic activity discharge heavy metals into the environment. Natural sources include erosion, weathering of metal-rich rocks, bacterial activity, and volcanic eruptions. Whereas, anthropogenic activities include waste disposal, combustion of fossil fuels, industrial activities, and use of metal-containing fertilizers and practices in agricultural practices (Alengebawy *et al*. 2021) [1]. Due to the complexity of the soil environment and the specificity of the heavy metals, the ecological risk of heavy metal toxicity to earthworms requires further research. But still, all reported studies increase the knowledge about the toxicity of heavy metals to earthworms which in turn helps to prove that these soil creatures play an important role as pollution indicators.

Many studies give evidence about how earthworms show their potential as indicators of soil pollution. The presence of Cu, Cd, Pb, Cr, and Zn heavy metals affects the growth, reproduction, and survivability of earthworms. There was a decrease in body mass in the presence of mercury. The presence of heavy metals in soil has a negative impact on the survival and reproductive efficiency of *E. fetida*. One important thing is that the ecological categories of earthworms play a significant role as epigeic earthworms (*E. fetida*) can strictly regulate the tissue heavy metal concentration than endogeic worms (*M. posthuma*) because they are tolerant to heavy metals (Haung *et al*. 2021). Earthworms' sensitivity to soil pollution can vary, based on their ecological distribution, as different earthworm species possess unique feeding behaviors and habitat preferences.

Conclusion and future prospects

The concept of sustainability involves happy blinding between agricultural growth to meet the crisis and the protection and conservation of natural resources. It has simply meant growth not at the cost of the future. The present pace of soil degradation and environmental concerns of high input-intensive agriculture are some of the major issues in developing future strategies for sustainable agriculture. For sustainable food security the following approaches should be made:

- Development of farming systems with minimum loss to the environment.
- Biodiversity conservation.
- Minimize the use of water for irrigation.

Soil bio-resources have been recognized as the foundation for sustainable livelihood, food security and environment safety. The importance of earthworms cannot be ignored at this stage; they improve soil condition and clean the environment on a sustainable basis. Earthworms act as 'Ecosystem Engineer' converting waste into highly nutritive organic fertilizer. Both earthworms and their metabolic product (vermicompost) may work in sustainable food production by replacing the use of agrochemicals in crop production. Recently, many countries around the world have refused to take exported vegetables and fruits due to excessive use of pesticides from India. This problem could be overcome by following vermitechnology. Vermitechnology has multiple benefits, including increased soil productivity, and the production of vermiwash which has pesticidal and insecticidal properties. Vermicompost is rich in microbial diversity and plant-available nutrients, which in turn promotes plant growth. In short, we can say that switching over to sustainable agriculture by vermiculture can bring economic prosperity for the people, farmers, and the country with environmental security.

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